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A LAKE RANKING PROGRAMME CONDUCTED ON FORTY-THREE LAKES IN THE THUNDER BAY AREA

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A LAKE RANKING PROGRAMME
CONDUCTED ON FORTY-THREE LAKES
IN THE THUNDER BAY AREA

J. VANDER WAL and R. J. STEDWILL
ONTARIO MINISTRY OF THE ENVIRONMENT
September, 1975

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SUMMARY

Throughout the summer of 1973, 43 lakes in the Thunder Bay area were studied with the objective of attaining data which would lead to an understanding of water quality conditions when a lake ranking scheme was applied. Six parameters, involving biological, chemical and physical parameters, were incorporated in a ranking scheme in which a low level of biological productivity was considered an index of high water quality.

The results showed Loch Lomond and Arrow Lake to be of outstanding quality in this report. While the majority of the 43 lakes were of considerably lower quality than the two above, none of them was shown to be critically impaired from a productivity standpoint.

Emphasis in the report is placed on the relevance of each parameter in the ranking scheme. A critical evaluation of the way in which these parameters are utilized is also made.

GENERAL LOCATION OF THUNDER BAY
STUDY AREA



FIGURE 1

INTRODUCTION

With a general increase in leisure time, Ontario lakes have become an expanding recreational source for many people. With this increase, the public has become more aware of the value of preserving these lakes to ensure their use, not only for this generation but also for those to follow. It has become clear that investigations must be continually undertaken to ascertain the existing water quality status of different lakes; to determine their susceptibility to damage, and to establish criteria through which they can be protected.

During the summer of 1973, biology personnel of the Ministry of the Environment sampled 43 lakes within a 50-mile radius of the city of Thunder Bay (a list of the study lakes is presented in Table 3). The physical, chemical and biological data collected (Table 1) have been incorporated into a ranking scheme in order to gain an understanding of the comparative water quality of these lakes. This ranking scheme was developed by the Ministry of the Environment in conjunction with Hough, Stansbury and Associates, Landscape Architects and Site Planners, as well as the Ministry of Natural Resources, to establish criteria for the maximum cottage development potential of Southern Ontario recreational lakes.

The water quality rationale, as stated by Michalski and Conroy (1972), is based on a scheme in which high water quality is directly associated with low biological productivity, while also considering aspects which are detrimental to the existence of healthy sport fish populations. Furthermore, the level of biological productivity, or trophic status, is related to lake classification characterized by the process of eutrophication.

Table 1. Parameters used in ranking of lakes in the Thunder Bay Study area and their relation to high water quality.

<u>Parameter</u>	<u>Relation to High Water Quality</u>
Secchi disc depth	Direct
Chlorophyll <u>a</u>	Inverse
Oxygen distribution in mid-summer	Direct
Mean depth	Direct
Morpho-edaphic index	Inverse
Fe to P ratio in the hypolimnion under anaerobic conditions	Direct

The process of eutrophication is a natural one, yet it can be greatly accelerated by the unnatural influx of nutrient supplies. Run-off from fertile agricultural land, industrial wastes and domestic sewage can all accelerate the rate at which a lake becomes eutrophic.

Warm, shallow and highly productive lakes are termed "eutrophic". These lakes, which in the extreme are characterized by the presence of massive algal blooms and/or dense aquatic vegetation, offer little to those in pursuit of water-oriented recreation. On the other hand, those lakes termed "oligotrophic" are characterized by cold, clear and deep waters which are oxygen-rich and usually have a low biological productivity. These waters offer no impediments to swimming, boating and other related activities. Intermediate lakes of moderate productivity are termed "mesotrophic" and it is in this category that the majority of Ontario's surveyed lakes are grouped.

It has been found that in the aquatic ecosystem, availability of nutrients to the primary producers is a basic consideration in

controlling the level of productivity and hence, the associated level of water quality. Firm evidence of radically increased productivity in many recreational lakes has indicated that some have changed from high to low quality in a short period of time. These changes have occurred through increased nutrient input associated with human activities. In view of these factors, the importance of understanding the implications of human exploitation of recreational areas cannot be overstated.

DESCRIPTION OF STUDY AREA

The study area borders on the north shore of Lake Superior and is contained within a 50-mile radius of the city of Thunder Bay. The area is accessible by Highways 11 and 17 from the east, 11 and 17 from the west, and Highway 61 from the south. The study area has several distinct watersheds draining southward into Lake Superior.

Prior to settlement, the area was used as a major fur trading route. As the population increased, it was sustained by and is presently dependent on forest products, ore-concentrates shipment and handling of grain from the western provinces.

Recreational pursuits by local residents and tourists include angling for speckled, rainbow and lake trout, yellow pickerel, smallmouth bass and northern pike, as well as the hunting of moose, deer, bear and small game.

Geology

Describing the geology of the area, E. G. Pye states that the Lake Superior region lies within the Canadian Shield, an extremely

large area underlain by ancient sedimentary, igneous and metamorphic rock formed in Precambrian time. Periodically, the consolidated rocks of the region were covered by gravels, sands and clays laid down in the Cenozoic era in the Pleistocene epoch, when continental glaciers spread across the country.

Physical and chemical characteristics of a lake are very much dependent on the nature of the bedrock and surficial geology. Local vegetation and climate are also dependent on geologic formations to some degree.

The conglomerate, shale, sandstone and carbonate rocks of Proterozoic origin are restricted to the eastern portion of the study area and include the lakes of the Sibley Peninsula as well as Loon Lake and to some extent Bass Lake. This area contains 10 of the 43 study lakes.

A large area composed of acidic igneous and metamorphic rocks of Archean origin contains 12 of the study lakes. Seven of these are found approximately 25 miles north of Thunder Bay. The remaining 5 lakes are found approximately 50 miles west of the city. The majority of the remaining lakes in the study area are found in geological zones of Proterozoic, Animikie and Archean metasediments and metavolcanics. A detailed account of the bedrock geology can be obtained from the Ministry of Natural Resources, Division of Mines.

Surficial Geology

The surficial geology types found in the Thunder Bay study area are for the most part the result of glacial and lacustrine deposition activities.

Sand and silt ground moraine is found in the majority of the Sibley Peninsula as well as in an area bordering the rest of the study lakes, from Dog Lake in the north to Arrow Lake in the southwest. Sand, gravel, and boulders are found in a relatively narrow band, of a width not exceeding two miles, beginning in the Loon Lake area and proceeding almost continuously to the eastern tip of Whitefish Lake. Two distinct deposits of lacustrine origin are found in the area. The first type consists of two relatively large zones of varved or massive clay and silt. Lenore Lake is the only study lake found in this form of deposition. The second type, consisting of sand and fine sand, occupies a large area associated with the Kaministiquia River Valley and the city of Thunder Bay itself. None of the study lakes is found in this deposit.

Climate and Vegetation

The area receives an annual rainfall and snowfall of 68.6 and 203.2 centimetres (27.0 and 90.0 inches) respectively.

It is characterized by an average July temperature of 18°C (64°F) and a January temperature of -16°C (7°F).

The area is forest covered with mixed coniferous-deciduous stands predominating. The most important conifers are black and white spruce (Picea mariana and P. glauca), balsam fir (Abies balsamea), and jack pine (Pinus banksiana).

The most conspicuous deciduous stands are white birch (Betula papyrifera), trembling aspen (Populus tremuloides), and balsam poplar (Populus balsamifera).

Lake Morphometry

The lakes included in the ranking program in the Thunder Bay District show a diversity of physical characteristics. Depths range from that of Joeboy Lake, with a maximum depth of less than 1 metre, to Dog Lake, with a maximum depth exceeding 100 metres. Surface areas range from less than 300 acres for Mud Lake, to in excess of 40,000 acres for Dog Lake. Morphometric data, including surface area, maximum depth, mean depth and volume, are given for 30 representative lakes in Table 2.

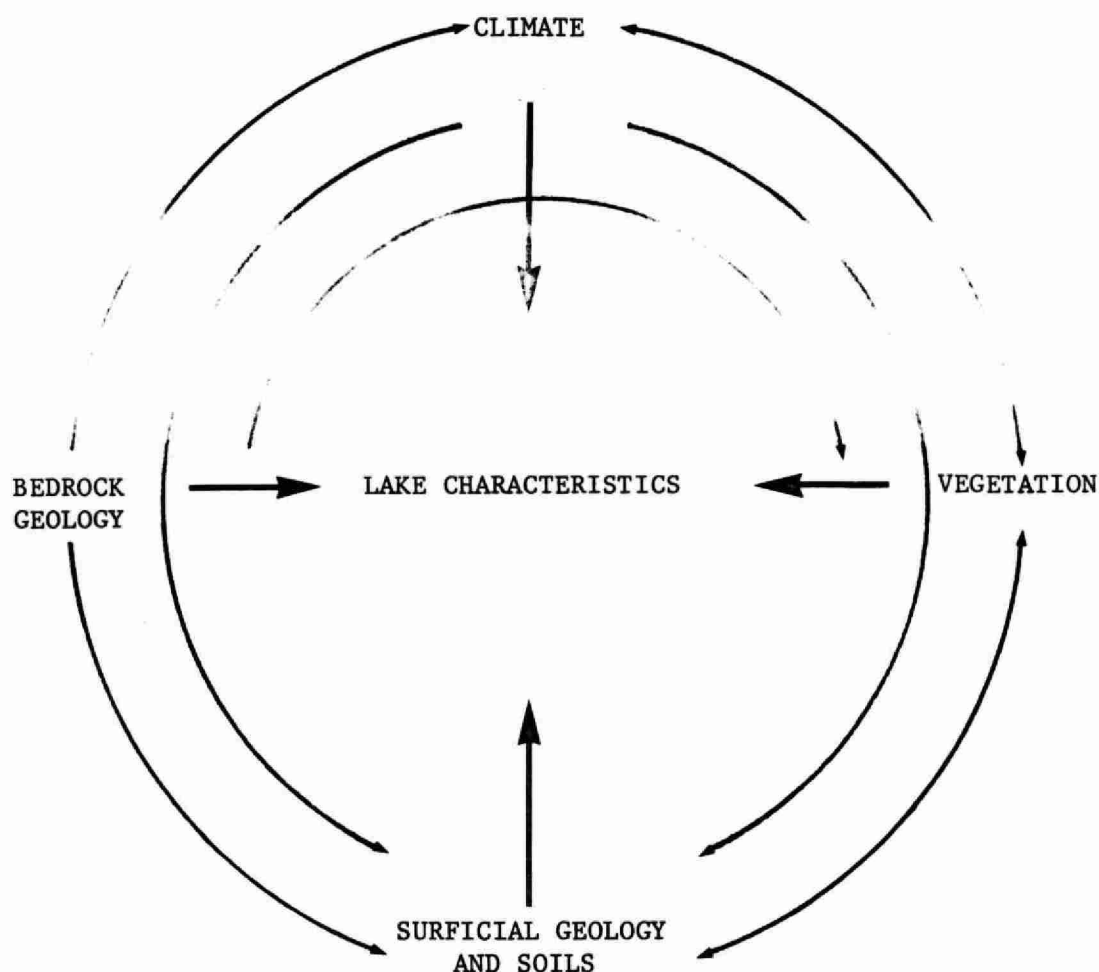
THE SIGNIFICANCE OF CLIMATE, GEOLOGY AND VEGETATION IN DETERMINING LAKE CHARACTERISTICS

Climate, geology and vegetation influence physical and chemical characteristics of lakes separately, as well as in a system of interrelationships, as depicted in Figure 2.

The climate of a region affects the level of biological productivity in lake waters by controlling water temperatures as well as controlling the amount of sunlight available for photosynthetic activity. Biochemical activity is known to increase proportionately with temperature increase, leading to an overall higher productivity during the warmest portion of the annual cycle; furthermore, the amount of precipitation regulates the quantity of materials washed into the lakes through run-off.

In the Thunder Bay area, cool climatic conditions restrict warming of lake waters for sustained periods of time and results in

Figure 2. A model depicting the interrelationships among factors affecting lakes.



ice-cover conditions, often exceeding six months of the year. During the period that lakes are covered by snow and ice, reduced temperatures and absence of solar radiation greatly affect primary production. In the absence of an air-water interface, diffusion of oxygen into the water ceases in late fall owing to ice cover. Only that oxygen supplied during the fall turnover is available to organisms actively utilizing this important chemical resource in respiration.

Table 2. Morphometric description of 30 representative lakes in the Thunder Bay Study area.

Lake	Area (Hectares)	Max. Depth (M)	Mean Depth (M)	Volume (Cubic Metres) ($\times 10^6$)
Pass	18.2	20.4	9.1	1.66
Lizard	194.2	2.4	1.5	2.96
Pounsford	259.0	9.4	6.7	29.70
Pickereel	64.7	3.4	1.8	1.18
Marie Louise	774.6	16.2	7.3	56.66
Silver	64.7	28.9	10.7	6.90
Big Pearl	24.3	3.4	1.2	.29
Elbow	16.2	18.3	6.1	.98
Bass	27.5	9.7	7.6	20.96
Loon	247.7	9.1	5.5	13.58
Walkinshaw	33.6	10.7	3.0	1.02
Hazelwood	283.3	10.7	9.1	25.90
Trout	32.4	5.5	3.7	1.18
One Island	283.7	10.7	6.1	17.29
Island	225.0	24.1	9.1	20.57
Two Island	225.0	18.3	7.6	17.14
McCormack	23.47	6.7	3.0	.71
Hawkeye	398.2	36.6	12.2	48.55
Warnica	16.2	4.6	3.7	.59
Barnum	61.5	10.7	4.6	2.81
Surprise	404.7	13.1	6.1	24.67
Hoof	337.5	6.1	2.7	9.25
Batwing	638.6	15.2	6.1	38.92
Pete	17.0	10.7	5.5	.93
Swallow	361.0	4.6	1.5	5.50
Arrow	3,387.0	54.9	27.4	929.41
Iron Range	233.1	6.1	2.5	5.82
Sandstone	725.2	23.8	10.7	77.36
Cloud	194.2	20.7	9.1	17.76
Lenore	224.6	13.7	6.4	14.37

Bedrock geology is particularly important in areas where outcrops, subject to weathering, influence run-off water characteristics as well as those areas where surface rock is in direct contact with lake waters. The effect of these formations is notable in their contribution to hydrogen ion concentrations in lakes. The presence of acid igneous rocks is no doubt partially responsible for the general acidic conditions of Northern Ontario lakes.

The vegetational structure of a watershed not only controls the amount of sediment washed into lakes by inhibiting erosion, but also ultimately contributes organic material to lake waters. Forests tie up large nutrient quantities, thus making these nutrients unavailable to the aquatic ecosystem. Furthermore, the coniferous forests in Northern Ontario typically create acid soil conditions in the decay process, further affecting the pH of drainage water.

As shown in Figure 2, the above factors are dependent on each other in a variety of ways, continually moving towards a state of equilibrium. Cool, moist climate, affecting vegetation cover, weathering and decay, results in the formation of podsol soils which are traditionally low in nutrients and high in acidity. The geology and resulting topography of an area influence climate as well as limiting the type of soil formation caused by mechanical and chemical weathering. Hence, not only are the characteristics of a lake dependent on the characteristics of the climate, geology and vegetation of an area, but these factors are also dependent on each other, resulting in a dynamic system of which the lakes are a part.

FIELD AND LABORATORY METHODS

Forty-three lakes (Figure 3) were selected in the Thunder Bay District for study. One criterion for selection was based on the logistics of sample collection; i.e., distance of lakes from Thunder Bay and whether lakes were accessible by road. Furthermore, data on the pH of lake waters were to be concurrently collected with lake ranking information. Since the selected lakes were within a 50-mile radius of the city of Thunder Bay, transportation of samples to the Thunder Bay Laboratory was available daily and sampling of each lake once every two weeks was possible. Physical characteristics and diversity of water uses were also considered in the selection of lakes. As a result, 7 of the lakes chosen were in provincial parks, 20 were moderately or heavily used as cottage lakes, and 15 were lightly used, mostly as camping and fishing areas.

Sampling began on May 14th and continued until August 31st, plus an additional sampling in October. During the first two weeks of sampling, access points and sampling stations were established.

One sampling station was established for each lake at its deepest point unless the depth exceeded 40 metres, in which case the sampling station was arbitrarily chosen at a point at which the depth was 40 metres or more.

Parameters which were utilized directly in the lake ranking scheme are given in Table 1, presented with their relation to high water quality. As previously stated, the lakes were visited on a

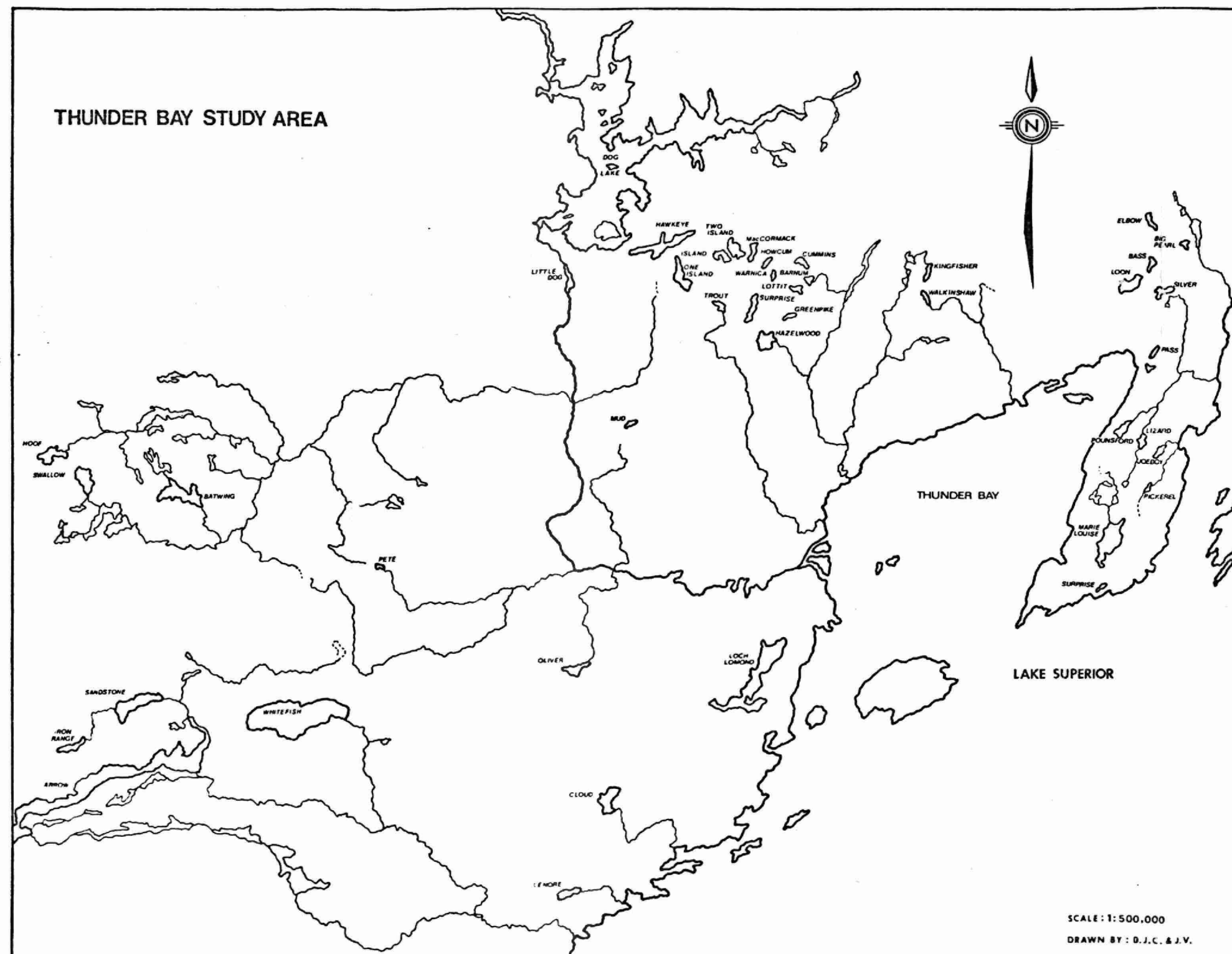


FIGURE 3 THUNDER BAY STUDY AREA

2-week cycle, resulting in each lake being sampled 8 times. Chlorophyll a and b, pH and Secchi depth information were collected on each visit while temperature profiles, oxygen distribution, sulphate, alkalinity, conductivity, iron, total phosphorus and total kjeldahl were collected monthly. Samples for determination of free CO₂ were collected during one interval from August 16th to August 30th. Total dissolved solids were determined from samples collected from July 2nd to July 16th. T.D.S. data were incorporated into the morpho-edaphic index.*

Chlorophyll a and b samples were collected in 1-litre glass bottles as composite samples from the euphotic zone. The depth of the euphotic zone was theoretically determined as twice the Secchi disc depth to yield approximately the level of 1% incident light. Samples were preserved in the field with 3 ml of 2% magnesium carbonate, placed in a cooler and transported to the Laboratory daily. At the Laboratory, 300-1000 ml of the sample were filtered through 1.2 μ "Millipore" filter paper with the use of a vacuum pump at approximately 14 P.S.I. The filtered samples were placed in plastic containers covered in aluminum foil and stored at -15^o to -20^oC. The chlorophyll concentrations were later determined by 90% acetone extraction followed by reading of percent wave length absorbance using a Beckman spectrophotomer. Chlorophyll concentrations in micrograms/

* The morpho-edaphic index was developed in 1965 by R. A. Ryder, a fisheries research biologist with the then Department of Lands and Forests (now Ministry of Natural Resources) to estimate potential fish production in north temperate lakes.

litre were determined using the following formulae:

Reference cell--90% acetone is used as a blank.

$$\text{Chlorophyll } \underline{a} = (15.6A_{665} - 2.0A_{645} - 0.8A_{630}) \times \frac{X}{L} \times \frac{1}{4}.$$

$$\text{Chlorophyll } \underline{b} = (25.4A_{665} - 4.4A_{665} - 10.3A_{630}) \times \frac{X}{XL} \times \frac{1}{4}.$$

Where L = volume in litres of original sample.

$$X = 5.$$

$$\frac{1}{4} = \text{factor for 4 cm cuvette.}$$

$$A = \% \text{ absorbance (at X nanometres).}$$

Oxygen and temperature regimes were determined directly in the field with a YSI model 54 oxygen-temperature metre.

Samples for determination of other chemical parameters were collected from the epilimnion and from the hypolimnion. These samples were taken with a 2-litre Kemmerer water sampler, 1 metre from the surface and 1 metre from the bottom, respectively; placed in 1-litre glass bottles and transported to the Laboratory for analysis. The methods for analysis were carried out as per Standard Methods for the Examination of Water and Waste Water, Twelfth Edition, American Public Health Association, New York.

Analyses in most cases were accomplished within 24 hours of sample collection. The majority of morphometric data were made available by the Ministry of Natural Resources.

The method of compiling ranks for the parameters given in Table 1 proceeded as follows: A range of 0-10 was chosen to delineate the lower and upper limits of possible ranks. For each parameter, the lake with the highest or lowest value, depending on the relation dictated in Table 2, was given a rank of 10 and conversely a rank of 0

was assigned to the lake having the poorest value for the particular parameter relation. Ranks for the balance of the lakes were computed in the following manner:

$$\text{Lake rank} = \frac{10 (x-y)}{z-y}$$

Where x is the value for the lake

y is the minimum value for all lakes

z is the maximum value for all lakes.

When the relationship between the parameter and high water quality is inverse, such as chlorophyll a, the formula was reversed:

$$\text{hence, Lake rank} = \frac{10 (z-x)}{z-y}$$

When the ranks for individual parameters for each lake were computed, they were averaged to give a final lake rank. Subjective assignment of values for the type of oxygen distribution is explained in the discussion portion of this report.

RESULTS AND DISCUSSION

As stated in the introduction, the ranking scheme is based on a comparison of lakes on the basis of parameters which reflect in either a direct or indirect manner the trophic status of a lake. Classification of lakes into intergrading classes of oligotrophic, mesotrophic and eutrophic indicates progressive aging as a result of increased availability of nutrients to the primary producers in the system at a bio-chemical level and gradual sedimentation of the lake basin at a physical level. Nutrients are incorporated into the

photosynthetic algal and macrophyte plant stocks. Algae provide sustenance for zooplankton which in turn are the food of invertebrates and small fish. This type of food chain proceeds in a variety of pathways until ultimately the nutrients are incorporated into higher consumer levels, in most cases, large predatory fish.

The system, however, is not linear but rather cyclical (Figure 4). Dead organisms and organic wastes decay at the lake bottom. Bacterial decomposition proceeds with the use of available oxygen, and in highly productive and stratified waters the depletion of this essential resource occurs in the hypolimnion. If oxygen in the hypolimnion becomes sufficiently depleted, decay of organic matter virtually ceases. As is the case in Lake Erie in Southern Ontario, large quantities of algae accumulate at the lake bottom and often masses of rotting vegetation are washed ashore. As stated in the introduction, the process of eutrophication or aging is a natural one, yet acceleration of the process is a certainty if nutrient supplies are unnaturally increased.

It is important to recognize the difference between natural and cultural eutrophication. A eutrophic lake, far from civilization, would be considered to have low water quality under the ranking scheme used in this study. However, a low rank does not imply that the water body is polluted. If, however, a lake received a low rank and was shown to be rapidly deteriorating as the result of an influx of nutrients associated with poorly treated sewage disposal, it can be inferred that cultural eutrophication is actively on-going and that the lake is currently being contaminated.

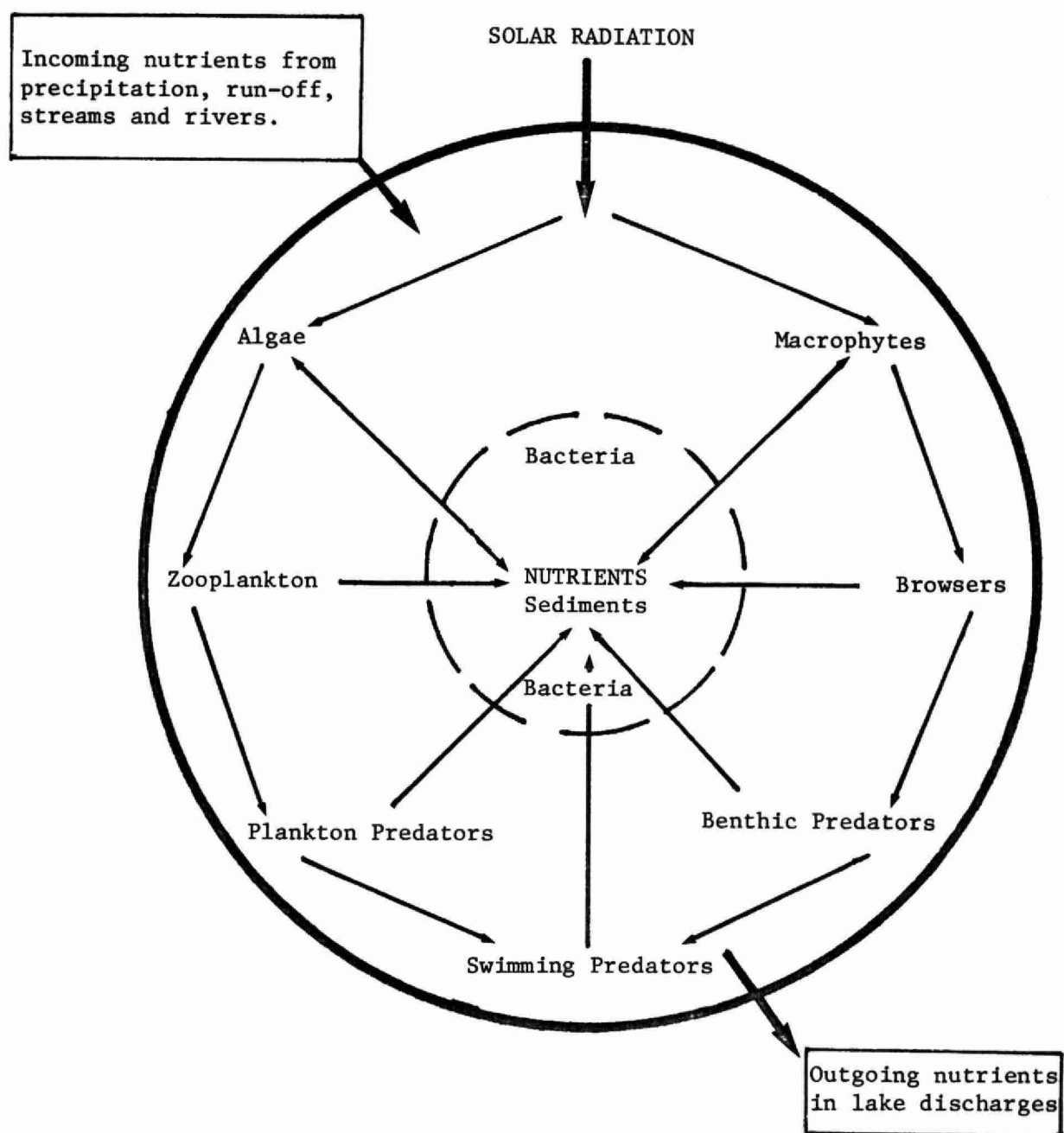
Water quality assessments, as described under the ranking program, yield a relative measure of trophic conditions which can be useful in predicting potential biological problems in recreational lakes. It should be noted, however, that in actual planning of a development, a holistic approach must be accomplished. Such an approach should include evaluation of data on many other parameters such as total watershed conditions, existing shoreline development, water uses and any potentially deleterious influences from other sources, particularly those which are cultural.

Each parameter listed in Table 1 is used to assess measurable components of the aquatic ecosystem which reflect the trophic status of a lake. The results of the survey are given in Table 3. The significance of each parameter and its relationship to the lakes studied in the Thunder Bay District are considered in turn.

Secchi Disc Depth

Secchi disc readings measure the transparency of lake water to incident light by lowering a disc, 20 cm in diameter with alternate black and white quadrants, into the water on the shaded side of the boat. The depth at which the disc disappears is noted as well as the depth at which it reappears. The mean of the two readings is termed the Secchi disc depth. This depth approximately corresponds to the level of 5% light incidence. Michalski et al found that twice the Secchi disc depth approximates the level of 1% incident light and this level has been found sufficient to support active photosynthesis by algae.

Figure 4. A simplified model depicting food and nutrient relationships in lakes.



Although wide variations in the physical characteristics of different waters may introduce some error when comparisons of lakes are attempted, Hutchinson (1957) states that "When a relatively homogeneous group of lakes is compared there is a high correlation between the Secchi disc transparency and transmission." It is felt that lakes in the Precambrian Shield, despite differences, are sufficiently similar in nature to term them "relatively homogeneous" and hence warrant comparisons of Secchi depths as a meaningful index of light transmission.

Table 3 shows the lowest Secchi depth in Swallow Lake, Trout Lake and Whitefish Lake with mean readings of 1.6 metres, 1.7 metres and 1.7 metres respectively. By far, the highest recorded Secchi depths were found in Arrow Lake with a mean reading of 8.3 metres.

Chlorophyll a

The measure of chlorophyll a in samples from the euphotic zone represents the amount of photosynthetic pigment present. This, in turn, reflects the degree of primary productivity at any one time. The mean of samples taken over the summer months is a reasonable measure of average productivity. Stedwill has stated that values in the range of 2.0-5.0 $\mu\text{g/l}$ indicate low to moderate algal populations. Levels of 5.0-10.0 $\mu\text{g/l}$ constitute common conditions which normally do not impede recreational activity. High algal populations are present at levels of 10.0-15.0 $\mu\text{g/l}$ and levels exceeding this constitute deterioration of the lakes' potential for recreational activities and aesthetic qualities.

Hoof Lake was the only lake in which the mean chlorophyll a level exceeded 5.0 $\mu\text{g}/\text{l}$. The maximum recorded was that of 14.8 $\mu\text{g}/\text{l}$ in August. The lowest mean level recorded was that of Arrow Lake at 1.3 $\mu\text{g}/\text{l}$. The majority of the remaining lakes were found to have levels below 3.0 $\mu\text{g}/\text{l}$ over the summer months.

Brown (1972) found that plotting Secchi disc depths against chlorophyll concentration of Southern Ontario lakes yielded a hyperbolic-like curve. This curve is shown in Figure 5 along with the Secchi disc chlorophyll values determined from lakes in the Thunder Bay study area.

Dissolved Oxygen Distribution

The type of oxygen distribution found in a lake in mid-summer is the product of: (a) production of oxygen by photosynthetic organisms in the presence of sunlight, (b) depletion of oxygen by respiring organisms, (c) the stability of thermal density stratification, and (d) absorption of oxygen from the atmosphere.

Increased biological production accompanied with increased hypolimnetic oxygen consumption in the biodegradation process usually results in a deficit in the oxygen balance as more oxygen is consumed in respiration than is being produced photosynthetically. This is particularly significant when water temperatures are at a maximum since the likelihood of stable lake stratification is increased and oxygen saturation varies inversely with temperature. Oxygen availability, particularly in the hypolimnion, is a most important parameter controlling the biotic community structure.

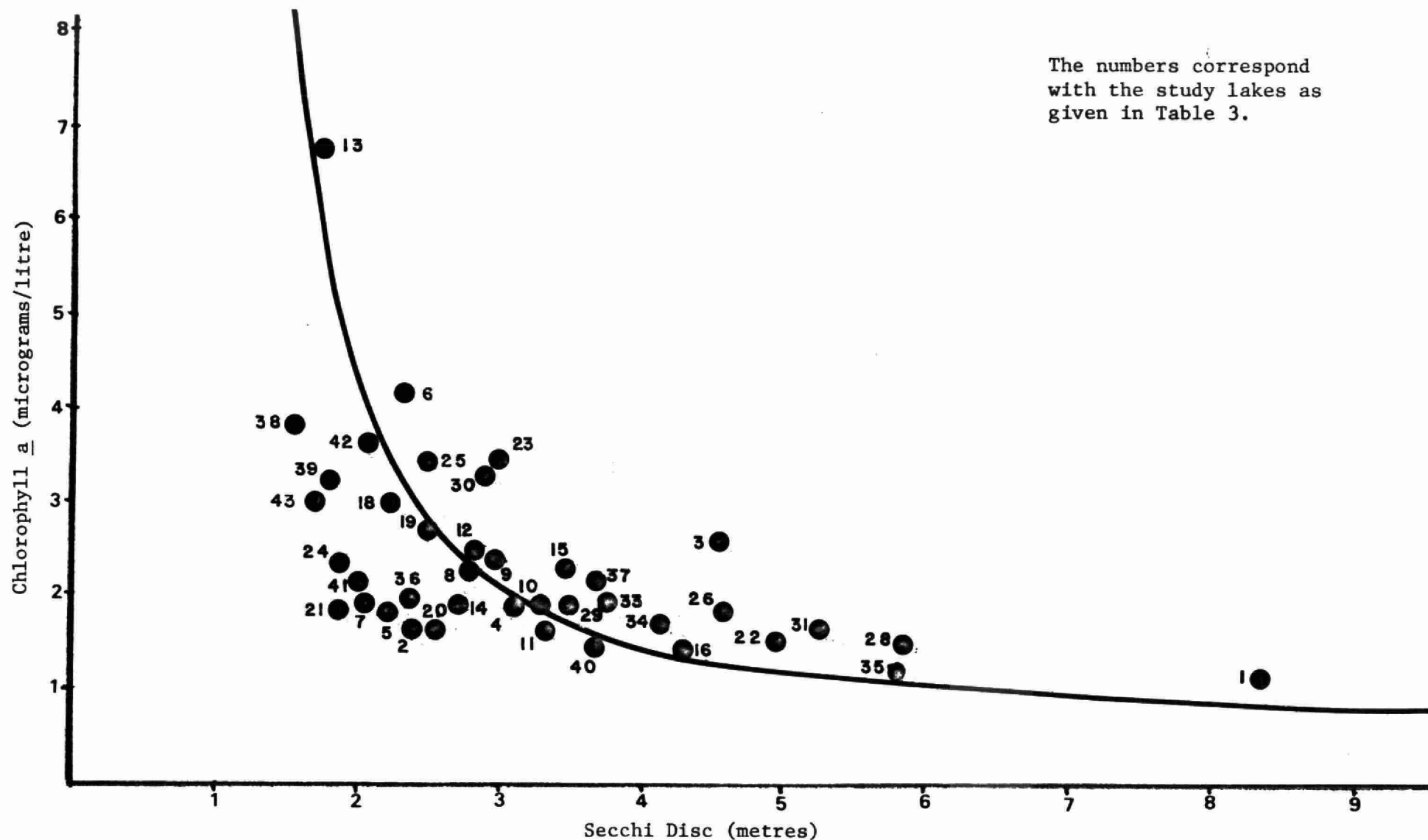


Figure 5. The relationship between chlorophyll a concentrations and Secchi disc depths found in 43* lakes in the Thunder Bay area. The values shown are mean values of collections made throughout the summer of 1973.

* Three lakes (Pickerel, Joeboy and Mud Lakes) are not included because of erroneous Secchi disc values.

The classification of oxygen distributions originating with Aberg and Rodhe (1942) is used in this lake ranking study. A rank of 7 is assigned to lakes with orthograde distributions, signifying that oxygen levels are fairly uniform from the surface waters to the hypolimnetic waters. Conversely, a rank of 1 is assigned to the lakes found to be anaerobic 1 metre from the bottom in mid-summer. Anaerobic conditions effectively cripple the process of biological degradation of organic material at the lake bottom.

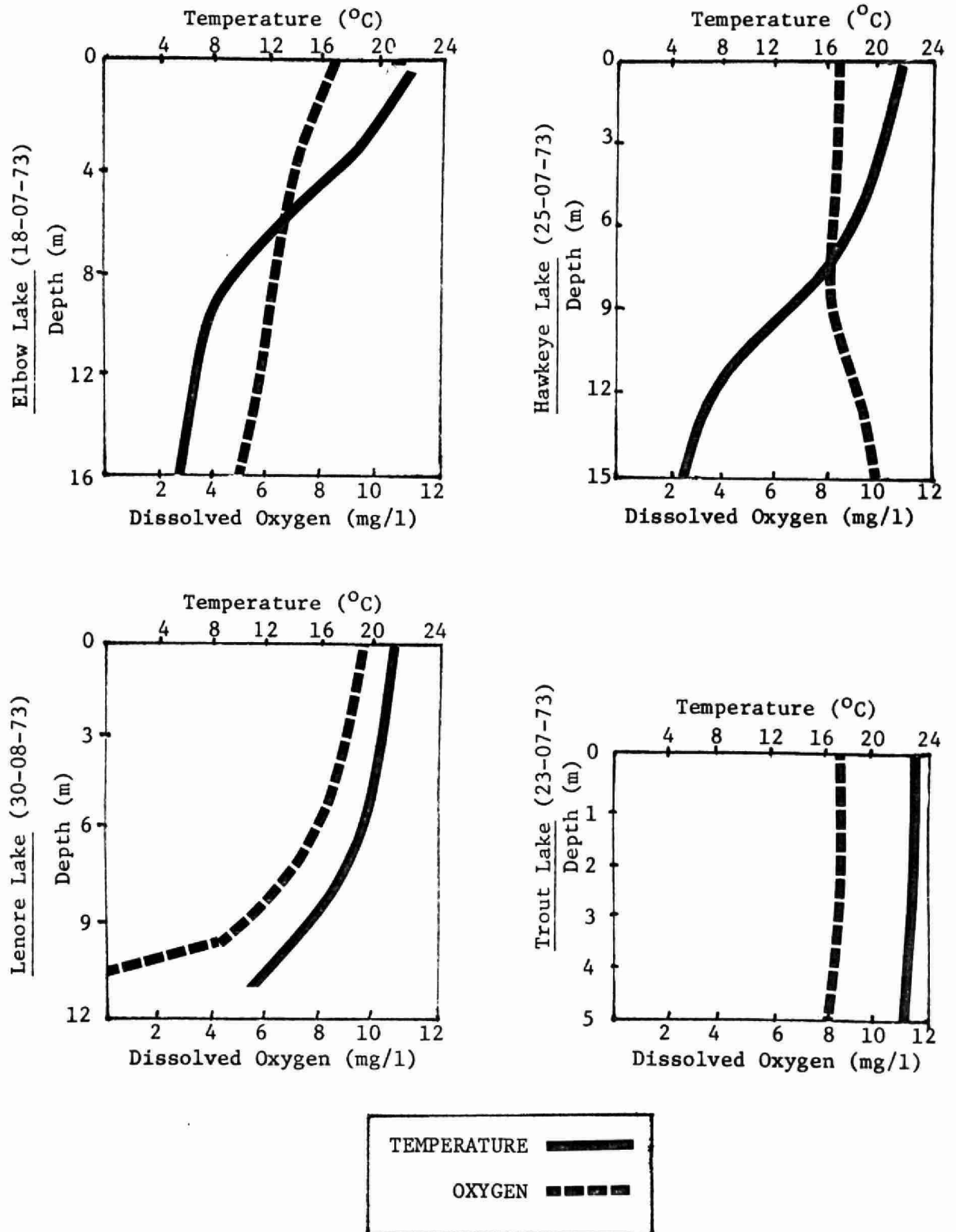
Clinograde distributions are characterized by diminishing oxygen levels from the lake surface to the bottom, without achieving anaerobic conditions. Clinograde lakes were given a value of 3. This rank was also applied to positive heterograde conditions where maximum oxygen levels were associated with the metalimnion or upper hypolimnial waters. Table 3 illustrates the proportion of study lakes found in each of the 4 groups.

The intermediate values of 3 are assigned to reflect some degree of oxygen depletion in the hypolimnion as a result of the biological utilization of this reserve.

Oxygen distributions are closely related to the temperature distribution or density stratification during the summer months. If a lake exhibited no stable temperature strata and oxygen concentrations were found to be uniform, then the distribution was classified as orthograde. This is rationalized on the basis of oxygen availability, even though it does not reflect trophic conditions.

Figure 6 shows graphical representations of the temperature and oxygen relationships for 4 lakes of different oxygen distribution

Figure 6. Mid-summer oxygen and temperature regimes of 4 representative lakes in the Thunder Bay area.



characteristics. It is noteworthy that only 4 of the 43 lakes studied were found to be anaerobic 1 metre from the bottom, indicating the general absence of this detrimental condition in the Thunder Bay area.

Morpho-edaphic Index (T.D.S. and Mean Depth) (M.E.I.)

R. A. Ryder (1964), in describing a method for estimating potential fish production of north temperate lakes, stated that yield is affected by: (a) morphometric, (b) edaphic (those factors related to soils), and (c) climatic factors. In applying a system whereby biological productivity can be estimated, only morphometric and edaphic conditions need be considered if the climate in the study area is relatively homogeneous. Hence, the productivity of a group of lakes in a discrete area can be predicted by a measure of the ratio of total dissolved solids to mean depth.

Total dissolved solids reflect, in some relationship, concentration of ions in lake waters, effectively giving an approximate indication of fertility. Concentrations of limiting nutrients in a body of water are a relevant index of potential productivity only where phytoplankton and macrophyte stocks can utilize this reserve; i.e., in the euphotic zone. Mean depth then becomes an important variable since as lake depth decreases, a greater proportion of the lake volume and the water-sediment interface are contained in the zone of photosynthetic activity and hence the efficiency of primary production is increased. The likelihood of stable density stratification is higher in moderately deep lakes as compared with relatively shallow lakes. It has been suggested that cold hypolimnial waters act as a

nutrient sink and make these nutrients unavailable to primary producers during long periods of time (Rawson, 1952). Furthermore, it has been shown that shallow waters develop higher temperatures than do deeper lakes, resulting in increased biological activity.

Although the M.E.I., strictly speaking, has been formulated to give approximations of fish yield, it is felt that the index must, for the same reasons that it reflects productivity at higher trophic levels, be applicable to productivity at a primary level. Since the definition of high water quality in this study is inversely correlated with biological productivity and since the M.E.I. gives an estimation of productivity, it is proposed that M.E.I. can be used meaningfully to compare relative productivity and water quality in the lakes of the Thunder Bay Study area.

The limitations of the M.E.I. in this ranking scheme are recognized in two important areas. In the first, as mean depth decreases, the M.E.I. is increased and conditions, such as are found in Joeboy Lake, both preclude the existence of sport fish species because of severe winter conditions and yield an M.E.I. value which becomes disproportionately high. In the case of Joeboy Lake, the M.E.I. value is 83.0. Secondly, it is understood that although an abiotic lake system might assume a low M.E.I. value, such conditions are not highly esteemed for recreational development, particularly from a sport-fisheries standpoint.

Iron to Phosphorus Ratio

The measure of the iron-phosphorus ratio in the lower hypolimnion was utilized in only 4 of the lakes in the study area. These lakes, being

the only ones showing anaerobic conditions 1 metre from the bottom in mid-summer, were Kingfisher, Pete, Surprise (Sibley) and Lenore Lakes.

Einsele (1936) found that in the presence of oxygen, ferric phosphate occurred as a precipitate in the bottom sediments. However, in the absence of oxygen, this compound is reduced to ferrous phosphate with a subsequent release of phosphate to solution. Since it is assumed that under anaerobic conditions, phosphates in the sediments are being released by the reaction, the Fe to P ratio gives relevant data with respect to the true phosphorus content in the lake system. In the study lakes, this ratio varied from 5.5-14.4. The low value indicates high phosphorus levels, probably the result of the precipitate reduction in the sediments. Conversely, a lower phosphorus content associated with the 14.4 value indicates that little ferric phosphate was present during the period of oxygenation.

CONCLUSION

The average ranks given for all parameters (Table 3) show Loch Lomond and Arrow Lake to have the highest ranks of 8.9 and 8.4 respectively. Twenty of the 43 lakes assumed ranks in the range of 4.1 to 5.0. Fifteen lakes were categorized in the 5.1-6.0 range while 6 were included in the range of 6.1-7.0.

It is interesting to note that no single lake or group of lakes was found to be of consistently low quality with respect to the parameters studied so as to give an average rank below 4.1. None of the lakes was found to be impaired to a degree which set it apart from

the conditions found in the majority of lakes in the study area.

The values given for Loch Lomond and Arrow Lake clearly set them apart from the average with respect to high water quality conditions. Should any single factor be chosen to account for this situation, mean depth, accompanied with the edaphic effects resulting from the size and kind of watershed drained, would appear to be the most significant. This seems especially true in the case of Loch Lomond since the mean depth value for that lake is 32.0 m and the amount of watershed area drained is minimal owing to its location in The Nor'Westers mountain range. A limited watershed area is also associated with Arrow Lake suggesting that the amount of in-flowing nutrients should be proportionately low. Dog Lake, the largest of the study lakes, was assigned a rank of 4.6. To a great extent, this low value is attributable to the fact that Dog Lake receives the drainage from a large low-lying area to the north via the Dog River system. Had mean depth data been available, the overall rank for this lake would certainly have been improved substantially.

Combined Ranking of Northern and Southern Ontario Lakes

Lake ranking data from 5 Southern Ontario lakes and 5 lakes from the Thunder Bay Study area are presented in Table 4. These lakes were selected by choosing a cross-section of lakes from the two areas on the basis of the average ranks achieved in the separate studies. The ranking program in Southern Ontario includes data from 21 lakes in the Muskoka Lakes area.

Application of the ranking scheme to the combined data resulted in Lake Joseph assuming a rank of 9.5 with Loch Lomond following

with a value of 9.0. Lake Joseph has traditionally been accepted as a lake with outstanding water quality with respect to high levels of light transmission and low biological productivity.

Oliver Lake received a rank of 7.3 in Table 4, compared with 7.0 in Table 3. This lake was the only one of the Thunder Bay lakes which experienced an increase in rank. Conversely, only 1 lake of the Southern Ontario group experienced a decrease in rank value. This was Lake Joseph with a decrease from 9.7 to 9.5.

Although the comparison of data presented in Table 4 is of interest, the validity of comparing the average ranks may be questioned. It is accepted that the ranking scheme is most valuable when applied to a group of lakes which are subject to similar physical controls such as climate and geology. In the case of the 2 Ontario lake groups, it is possible that some of these physical conditions are sufficiently dissimilar to cause problems in comparison. One example of this may be found in the Secchi depth and chlorophyll a data. As previously stated, a relationship between these two parameters has been established. Generally, this relationship is an inverse one in which an increase in chlorophyll a concentration is accompanied with a decrease in light transmission and hence a decrease in the Secchi depth. The mean values for Secchi depth and chlorophyll a concentrations for the 22 lakes of Southern Ontario were 4.64 metres and 3.61 micrograms/litre respectively. In 40 lakes in the Thunder Bay area, these mean values were 3.20 metres and 2.26 micrograms/litre. Although the same mean depth values are not expected, a similar relationship between parameters is expected if controlling factors for each system are identical.

If we take the Northern Ontario mean for each parameter as a base-line datum (S.D. mean 3.20 and chlorophyll a mean 2.26), we would expect an increase in light transmission to be accompanied by a decrease in the chlorophyll a concentration. In the Southern Ontario group, this is not the case since a higher Secchi depth (4.64 metres) is accompanied with a chlorophyll a concentration which is higher than that found in Northern Ontario (3.61 micrograms/litre). This suggests that some factor or factors are in operation in Northern Ontario impeding light transmission, independent of algal populations. This, in itself, is obvious except that the same factor or factors must therefore be either absent or operating at a lesser level in the Southern Ontario lakes chosen. Furthermore, there lies the possibility that other dissimilarities, although they may not be obvious from the data presented, could affect the validity of the comparisons in Table 4.

Other Considerations

(a) Oxygen Distribution: Shallow lakes, because they are susceptible to constant mixing as a result of wind influences, are often found to resist thermal stratification. These lakes consequently display orthograde oxygen distributions and receive ranks of 10.0 for this parameter. In view of the fact that for some shallow lakes, oxygen availability in the lower waters is a result of physical controls rather than biochemical controls, the possibility exists that the assignment of ranks to unstratified lakes may lead to less than accurate assessments. Although supporting data are unavailable, oxygen levels during long periods of ice-cover might become sufficiently low as to

limit the value of the ranking program carried out only in the open-water months.

(b) Iron to Phosphorus Ratio: The use of the Fe-P ratio as a parameter of equal weighting with respect to the other selected parameters is questionable. If a lake is found to exhibit an oxygen regime which is distributed in a clinograde manner, a rank of 3.3 is assigned, whereas anaerobic conditions result in a rank of 0.0. In the case of Kingfisher Lake, anaerobic conditions in the lower hypolimnion resulted in a rank of 0.0 for oxygen distribution. The Fe-P ratio, however, compensates for this low value if low levels of phosphorus are associated with the sediments. For Kingfisher Lake, a high Fe-P ratio of 14.4 resulted in a rank of 10.0 for that parameter. Averaging all the ranks resulted in a final rank of 4.8. If the oxygen distribution for that lake had been found to be clinograde, receiving a rank of 3.3, the deletion of the Fe-P ratio as a parameter would have resulted in an average value of 4.5 had all the parameters remained the same. This difference in average ranks may not appropriately reflect the water quality differences between lakes with oxygenated hypolimnia and anaerobic hypolimnia.

(c) Mean Depth: The use of mean depth as a parameter of equal weighting is clearly justifiable because of its importance in trophic classification of lakes, but it should also be recognized that this criterion is reflected in several of the other parameters. The contribution of mean depth to M.E.I. values is obvious by definition. Chlorophyll a concentrations must be related to the M.E.I. since they are both productivity indices. Secchi disc depths are related to chlorophyll a

concentrations discussed earlier. Mean depth, then, has a more significant role in the ranking than would be implied by its use as a single parameter. Since mean depth exerts such a great influence on the ranking scheme, it is felt that in order to obtain the most meaningful ranking results, comparisons of trophic status should be considered in groups of lakes that share a common range of values for this morphometric characteristic. This is to say that lakes which are sufficiently shallow to restrict the existence of higher trophic levels as a result of winter kill conditions (Joeboy Lake, mean depth--.5 metres) may not yield valid results when compared with deep lakes (Loch Lomond, mean depth--32.0 metres) since the biotic and physical structures of deep lakes are controlled by a very different set of factors. Some obvious problems encountered have already been discussed in the consideration of the M.E.I.

The above considerations imply that modifications in the selection of study lakes and in the weighting of parameters might improve the value of the ranks, yielding a more meaningful distribution of values within the range of 0-10. These changes, however, would not result in significant alterations to the relative rank positions which the lakes have assumed in Table 3.

Outstanding water quality differences are certainly obvious by this scheme. Had there been lakes in the study group which were exceptionally vulnerable to cultural eutrophication, because of presently impaired conditions, this fact would have become obvious in the final ranking. It is felt that the results can be meaningfully interpreted within the context of the originally described ranking scheme, when

this information, integrated with many other factors, is utilized in resource planning.

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TABLE 3. Results of Six Parameters from Forty-Three Study Lakes in the Thunder Bay Area.

LAKE	OXYGEN DISTRIBUTION	VALUE	RANK	Fe/P ratios in the hypolimnion under anaerobic conditions 1 m from bottom		Secchi Disc Depth (m)			Chlorophyll a µg/l composite samples from Euphotic Zone			Mean Depth (m)		Morpho-Edaphic Index		AVERAGE RANK
				VALUE	RANK	RANGE	MEAN	RANK	RANGE	MEAN	RANK	VALUE	RANK	VALUE	RANK	
1. Arrow L.	b (S)	3	3.3	-	-	6.1 - 10.5	8.3	10.0	1.2 - 1.4	1.3	10.0	28.5	8.9	0.61	10.0	8.4
2. Barnum L.	b (S)	3	3.3	-	-	1.8 - 3.0	2.4	1.2	1.1 - 2.6	1.7	9.3	4.8	1.3	2.5	9.7	5.0
3. Bass L.	b (S)	3	3.3	-	-	..0 - 6.1	4.5	4.3	1.6 - 4.0	2.8	7.3	8.0	2.3	2.9	9.7	5.4
4. Batwing L.	b (U.S.)	3	3.3	-	-	2.7 - 3.9	3.1	2.3	2.1 - 2.8	1.9	8.9	6.3	1.8	3.1	9.7	5.2
5. Big Pearl L.	a (U.S.)	7	10.0	-	-	1.2 - 3.0	2.3	1.0	1.0 - 3.0	1.9	8.9	1.3	0.3	17.0	8.0	5.6
6. Cloud L.	b (S)	3	3.3	-	-	2.1 - 2.7	2.4	1.2	2.1 - 7.4	4.1	4.9	9.5	3.0	1.3	9.9	4.5
7. Cummins L.	b (S)	3	3.3	-	-	1.8 - 2.7	2.1	0.7	1.2 - 2.5	1.8	9.0	3.2*	0.9	4.5	9.5	4.7
8. Dog L.	b (S)	3	3.3	-	-	2.2 - 3.1	2.8	1.8	1.8 - 4.0	2.3	8.1	-	-	-	-	4.6
9. Elbow L.	b (S)	3	3.3	-	-	2.4 - 4.1	3.0	2.1	1.1 - 2.4	1.7	9.3	6.3	1.8	1.6	9.9	5.3
10. Greenpike L.	a (U.S.)	7	10.0	-	-	2.1 - 4.2	3.2	2.4	1.2 - 2.4	1.8	9.0	1.6*	0.4	11.5	8.7	6.1
11. Hawkeye L.	b (S)	3	3.3	-	-	2.9 - 3.6	3.3	2.5	1.2 - 2.2	1.6	9.4	12.6	3.8	1.8	9.8	5.8
12. Hazelwood L.	b (S)	3	3.3	-	-	1.8 - 3.9	2.9	1.9	1.0 - 2.4	1.5	9.6	9.5	2.9	2.0	9.8	5.5
13. Hoof L.	a (U.S.)	7	10.0	-	-	1.2 - 2.4	1.8	0.3	2.9 - 14.8	6.8	0.0	3.0	0.7	6.5	9.3	4.1
14. Howcum L.	b (S)	3	3.3	-	-	1.8 - 3.3	2.7	1.6	1.0 - 2.8	1.8	9.0	2.0*	0.5	9.1	8.9	4.7
15. Iron Range L.	b (U.S.)	3	3.3	-	-	3.0 - 3.9	3.4	2.7	1.0 - 3.9	2.4	8.0	2.5	0.7	11.6	8.7	4.7
16. Island L.	b (S)	3	3.3	-	-	3.3 - 5.8	4.2	3.9	1.0 - 2.0	1.4	9.8	9.5	2.8	1.5	9.9	5.9
17. Joeboy L.	a (U.S.)	7	10.0	-	-	Bottom	0.6	-	1.2 - 3.5	1.9	8.9	0.5*	0.0	83.0	0.0	4.7
18. Kingfisher L.	c (S)	1	0.0	14.4	10.0	2.1 - 2.4	2.3	1.0	1.8 - 4.3	2.8	7.3	4.1*	1.2	4.4	9.5	4.8
19. Lenore L.	c (S)	1	0.0	8.3	3.2	2.1 - 3.3	2.6	1.5	1.3 - 4.2	2.4	8.0	6.6	1.9	3.0	9.7	4.1
20. Little Dog L.	a (U.S.)	7	10.0	-	-	2.2 - 2.7	2.5	1.3	1.5 - 1.7	1.6	9.4	-	-	-	-	6.9
21. Lizard L.	a (U.S.)	7	10.0	-	-	1.5 - 2.1	1.8	0.3	1.4 - 3.3	1.9	8.9	1.6	0.4	32.0	6.2	5.2
22. Loch Lomond	a (U.S.)	7	10.0	-	-	3.8 - 5.4	4.9	4.9	1.3 - 1.6	1.4	9.8	32.0	10.0	0.38	10.0	8.9
23. Loon L.	b (S)	3	3.3	-	-	2.4 - 4.1	3.0	2.1	1.8 - 4.0	3.4	6.2	6.0	1.7	2.0	9.8	4.6

TABLE 3. Results of Six Parameters from Forty-Three Study Lakes in the Thunder Bay Area.

Page 2

LAKE	OXYGEN DISTRIBUTION	VALUE	RANK	Fe/P ratios in the hypolimnion under anaerobic conditions 1 m from bottom		Secchi Disc Depth (m)			Chlorophyll a µg/l composite samples from Euphotic Zone				Mean Depth (m)		Morpho-Edaphic Index		AVERAGE RANK
				VALUE	RANK	RANGE	MEAN	RANK	RANGE	MEAN	RANK	VALUE	RANK	VALUE	RANK		
24. Lottit L.	b (S)	3	3.3	-	-	1.3 - 2.4	1.9	0.4	1.5 - 3.5	2.3	8.1	3.0 [*]	0.7	4.6	9.5	4.4	
25. MacCormack L.	b (S)	3	3.3	-	-	1.8 - 3.0	2.5	1.3	1.8 - 7.9	3.5	6.0	3.2	0.8	4.3	9.5	4.2	
26. Marie Louise L.	b (U.S.)	3	3.3	-	-	1 - 5.5	4.5	4.3	1.0 - 3.1	1.9	8.9	7.6	1.8	5.0	9.4	5.7	
27. Mud L.	a (U.S.)	7	10.0	-	-	Bottom	1.8	-	2.0 - 4.4	2.9	7.0	1.3 [*]	0.3	20.0	7.6	6.2	
28. Oliver L.	b (S)	3	3.3	-	-	5.2 - 8.3	5.8	6.3	1.0 - 1.9	1.4	9.8	23.0	7.4	0.59	10.0	7.0	
29. One Island L.	b (S)	3	3.3	-	-	2.7 - 4.1	3.5	2.8	1.0 - 4.0	1.7	9.3	6.3	1.8	3.1	9.7	5.4	
30. Pass L.	b (S)	3	3.3	-	-	2.7 - 3.6	2.9	1.9	1.5 - 5.4	3.3	6.4	9.5	3.0	3.3	9.7	4.9	
31. Pete L.	c (S)	1	0.0	5.5	0.0	3.9 - 6.4	5.2	5.4	1.5 - 2.2	1.8	9.0	5.7	1.6	2.8	9.7	4.3	
32. Pickerel L.	a (U.S.)	7	10.0	-	-	Bottom	1.4	-	1.2 - 5.7	3.5	6.0	2.0	.59	18.2	7.8	6.1	
33. Pounsford L.	b (S)	3	3.3	-	-	2.7 - 4.5	3.7	3.3	1.2 - 4.4	2.1	8.5	7.0	1.7	4.2	9.5	5.3	
34. Sandstone L.	b (S)	3	3.3	-	-	3.6 - 6.1	4.1	3.6	1.2 - 2.8	1.8	9.0	11.0	3.3	14.5	8.3	5.5	
35. Silver L.	b (S)	3	3.3	-	-	5.2 - 7.9	5.8	6.3	1.0 - 3.1	1.6	9.4	11.0	3.4	3.0	9.7	6.4	
36. Surprise L. (Gorham Twp.)	b (S)	3	3.3	-	-	1.8 - 3.0	2.4	1.2	1.7 - 2.4	1.9	8.9	6.3	1.8	3.6	9.6	5.0	
37. Surprise L. (Sibley)	c (S)	1	0.0	8.2	2.9	2.1 - 4.5	3.6	3.0	1.2 - 3.8	2.3	8.1	9.6 [*]	2.8	4.0	9.6	4.4	
38. Swallow L.	a (U.S.)	7	10.0	-	-	1.3 - 2.1	1.6	0.0	3.1 - 5.0	3.9	5.3	1.6	0.4	9.1	8.9	4.9	
39. Trout L.	b (U.S.)	3	3.3	-	-	1.5 - 2.1	1.7	0.1	2.1 - 5.7	3.1	7.8	3.9	1.1	3.1	9.7	4.4	
40. Two Island L.	b (S)	3	3.3	-	-	2.7 - 4.5	3.6	3.0	1.0 - 2.1	1.5	9.6	8.0	2.3	1.7	9.8	5.6	
41. Walkinshaw L.	b (S)	3	3.3	-	-	1.8 - 2.7	2.0	0.6	1.1 - 2.2	1.8	9.0	3.2	0.8	7.5	8.9	4.5	
42. Warnica L.	a (U.S.)	7	10.0	-	-	1.8 - 2.4	2.1	0.7	1.6 - 6.6	3.5	6.0	3.8	1.1	2.5	9.7	5.5	
43. Whitefish L.	a (U.S.)	7	10.0	-	-	1.5 - 2.0	1.7	0.1	1.9 - 5.5	2.9	7.0	3.0 [*]	0.7	7.7	8.9	5.3	

a = orthograde

b = clinograde and/or positive and/or negative heterograde

c = anaerobic conditions at 1 m above bottom

OXYGEN DISTRIBUTION - Orthograde - 7
Clinograde - 3+ Heterograde - 3
- Heterograde - 3Anaerobic Condition
1 m from bottom = 1S. - Stratified
U.S. - Unstratified* Mean Depth based on limited available
data.

TABLE 4

A RANGED COMPARISON BETWEEN FIVE NORTH WESTERN ONTARIO LAKES AND FIVE SOUTHERN ONTARIO LAKES, (VALUES FOR EACH PARAMETER ARE GIVEN IN BRACKETS)

LAKE	MEAN DEPTH (M)		SECCHI DISC (M)		CHLOROPHYLL A		MORPHO-EDAPHIC INDEX		Fe/P		OXYGEN DISTRIBUTION		AVERAGE Rank
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	
Joseph	(25.3)	7.8	(8.1)	10.0	(1.1)	10.0	(0.5)	9.9	(-) ---	(a)	10.0		9.5
Little Lake Joseph	(17.0)	5.1	(5.9)	6.6	(2.5)	9.2	(0.7)	9.8	(-) ---	(b)	3.3		6.8
Skeleton Bar	(9.4)	2.6	(5.2)	5.5	(1.7)	9.7	(1.2)	9.6	(-) ---	(b)	3.3		6.1
Cold	(2.1)	.26	(3.4)	2.8	(5.4)	7.5	(3.1)	8.6	(34.7) 10.0	(c)	0.0		4.9
Riley	(1.5)	.07	(1.6)	0.0	(18.3)	0.0	(1.8)	9.3	(9.0) .38	(c)	0.0		1.7
Loch Lomond	(32.0)	10.0	(4.9)	5.1	(1.4)	9.8	(.38)	10.0	(-) ---	(a)	10.0		9.0
Sandstone	(11.0)	3.2	(4.1)	3.9	(1.8)	9.6	(14.5)	2.8	(-) ---	(b)	3.3		4.6
Mud	(1.3)	0.0	(1.8)	0.3	(2.9)	9.0	(20.0)	0.0	(-) ---	(a)	10.0		3.9
Oliver	(23.0)	7.1	(5.8)	6.5	(1.4)	9.8	(.59)	9.9	(-) ---	(b)	3.3		7.3
Lenore	(6.6)	1.73	(2.6)	1.5	(2.4)	9.2	(3.0)	8.7	(8.3) 0.0	(c)	0.0		3.5

(a) = orthograde

(b) = clinograde and/or positive and/or negative heterograde

(c) = Anaerobic conditions at 1m above bottom



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